CORRELATION PATTERNS OF MULTI-INFLUENCE MEASUREMENTS FROM CRUISE SHIPS IN THE MEDITERRANEAN SEA

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Abstract. *The increasing human interaction with the marine environment is bringing about a continuous growth in the ambient noise levels, which aggregates to the traditionally existing noises produced by natural sources and can affect, sometimes in a severe way, to the wellbeing of the marine fauna. To date studies have centred on the acoustic radiation, leaving in a second place the rest of radiations which also have a proven effect on marine life. In order to help to fill this gap, this study centres on analysing the levels and correlations patterns of several types of energy radiations in the marine environment: acoustic, electric, magnetic and seismic. The study is based on measurements with a multi-influence range system of a kind of vessels of increasing presence and importance worldwide as are the cruise ships. Results show not only a significant level of correlation between acoustic and seismic radiations by one side, and electric and magnetic by other side, but additionally a correlation degree among the four analysed radiations.*

Keywords: *Multi-influence measurements, acoustic level, seismic level, electric field level, magnetic field level, correlation patterns*

1 INTRODUCTION

Cruise ships distinguish from the rest of non-military vessels by the high number of persons travelling on them. By other hand, the leisure activity related with cruise shipping characterizes by a sustained growing during the last years, especially in the Mediterranean area, which bring about a parallel increase in the level of the energy globally radiated to the marine environment. Until now, main focus has been put on the potential harmful effects of acoustic radiations on the marine life, leaving at a secondary level the possible effects of the other underwater energy sources [1] such as electric and magnetic. Different wide-range institutions are aware of this issue, as reflected in specific regulations dictated in this field, as is the case of the Marine Strategy Framework Directive, MSFD [2].

The goal of this paper is to increase the knowledge about the characterisation of the electric, magnetic, acoustic and seismic signatures of cruise ships. Measurements are collected and processed by means of the SAES' manufactured Multi-Influence Range System (MIRS).

2 BACKGROUND ON MULTI-INFLUENCE SIGNATURES

When navigating, all the vessels independently of their shape and size emit a set of radiations that propagate underwater and configure their so-called multi-influence signature. This signature characterizes and identifies the specific vessel in a univocal form, in the same way that fingerprints identify to the human being. This multi-influence signature group together a set of individual signatures, between which are found: acoustic, seismic, electric (Fig. 1.) and magnetic [3].

An adequate study of these signatures since the starting phases of the vessel design allows taking into consideration appropriate measures to influence on their reduction. This reduction has effect on different areas, as: the increase of comfort of the crew and passengers of the vessels, the reduction of the marine environment pollution or a lower detectability of the vessels that affect on their security.

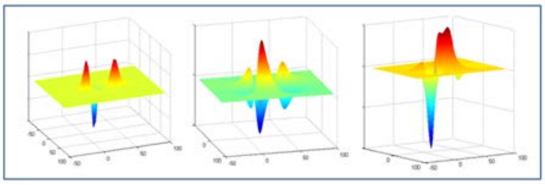

Fig. 1. Simulation of the electric field radiated by a vessel: longitudinal, athwartship and vertical components.

3 MEASUREMENTS DESCRIPTION

Measurements have been collected using the SAES' manufactured MIRS system (Fig. 2). MIRS incorporates a set of calibrated sensors that provide accurate measurements of the influences: acoustic, seismic, electric, magnetic and pressure.

Fig. 2. Underwater Sensor Units (USU) of the Multi-Influence Range System, MIRS.

A set of sixty (60) measurements have been used for analysis. Fig.3. shows the ships characteristics (Gross Tonnage –GT-, length and beam). The mean value of the GT is 51.400 tons, while the mean values of the length and the beam are 230 and 29 meters respectively.

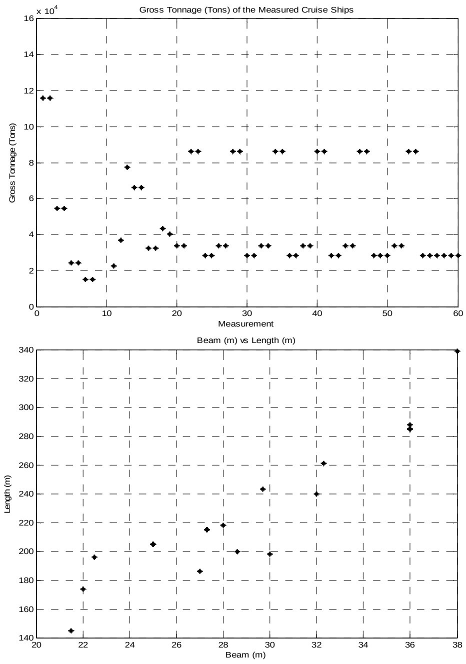

Fig.3. Values of Gross Tonnage (upper) and Length vs Beam (bottom) for the data set of cruise ships

With relations to the runs characteristics, Fig.4. shows the speed and the lateral offset (horizontal distance between the sensor and ship at CPA) of the ships during the measurements. The mean value of the speed is 6.12 knots while the mean value of the lateral offset is 22.75 meters.

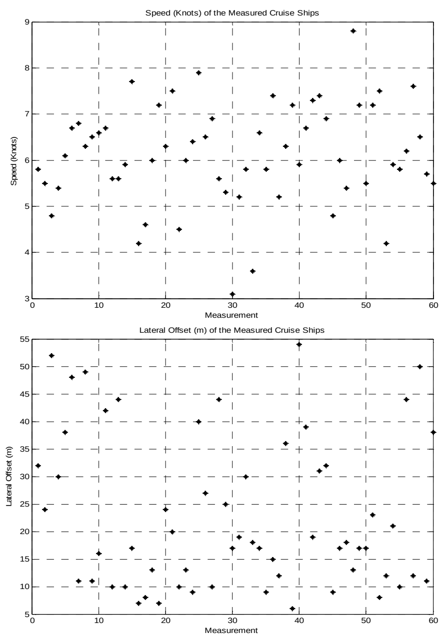

Fig.4. Speed (upper) and Lateral Offset (bottom) of the ships at CPA for the data set of cruise ships

4 MEASUREMENTS ANALYSIS

Fig. 5. shows typical electric (static and alternating), magnetic (static and alternating), seismic and acoustic time signals of a cruise ship.

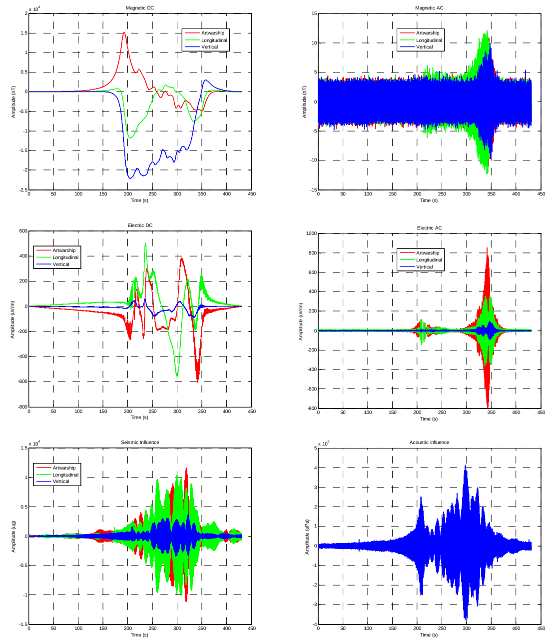

Fig.5. Typical Static (left-up) and alternating (right-up) electric, Static (left-middle) and alternating (right-middle) magnetic, seismic (left-bottom) and acoustic (right-bottom) signals radiated by a cruise ships.

Fig. 6. shows Broadband energy, One Third Octave typical electric (static and alternating), magnetic (static and alternating), seismic and acoustic time signals of a cruise ship.

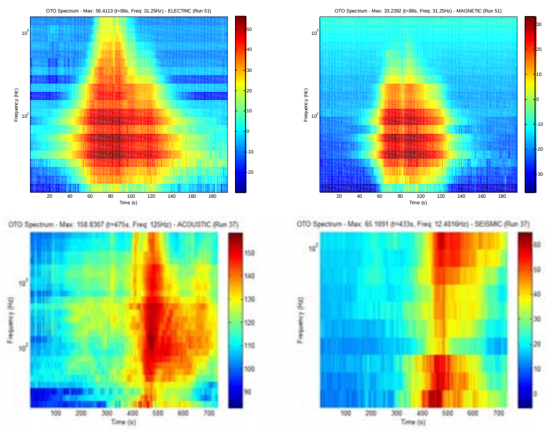

Fig. 6. Typical OTO of electric, (left-up), magnetic (right-up), acoustic (left-bottom) and seismic (right-bottom).

The study of correlation is divided into two stages: correlation between static (time domain) and alternating (frequency domain) energy distribution of each influence individually, and correlation between influences in both, time and frequency domains.

The time domain analysis consists on the computation of the time when the module of the static component is maximum. The analysed influences in the time domain are: static electric (UEP), static magnetic (SM), seismic and acoustic influences.

The frequency domain analysis consists on the computation of the time when the module of Spectral Power Density is maximum. The analysed influences in the frequency domain are: alternating electric (ELFE), alternating magnetic (AM), seismic and acoustic.

5 RESULTS

Fig. 7 shows the time (in seconds) when the maximum of the amplitude module of each influence is reached for all measurements.

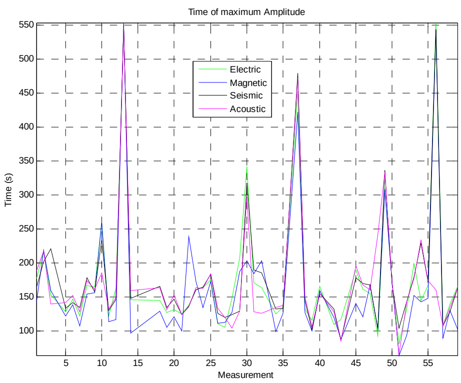

Fig.7. Time of the maximum of the module of each influence for all measurements.

Fig. 8 shows the time (in seconds) when the maximum of the module of the Spectral Power Density (SPD) is reached for all measurements.

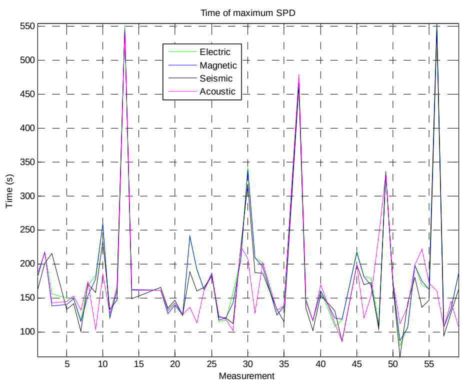

Fig.8. Time of the maximum of the Spectral Power Density of each influence for all measurements.

In order to compare the energy distributions in time and frequency domains of each influence, the difference between the time of the maximum of the amplitude module and the time of the maximum of the SPD module is computed for each measurement.

Table 1. shows the mean value of the differences in seconds, in meters and in %, relative to the length of the ships, between the time of the maximum of the amplitude module and the time of the maximum of the SPD module for each influence.

Influence	Time (s)	Range (m)	% Length
Electric	12	38	16
Magnetic	23	72	32
Seismic	9	30	13
Acoustic	14	44	19

Table 1. Mean value of the differences between the time of the maximum of the amplitude module and time of the maximum of the SPD module.

The influence with highest level of correlation between the energy in the time and frequency domains is the seismic. The lowest correlation is obtained for the magnetic influence. The electric and acoustic influences present the same correlation between the distribution in the time and frequency domains.

These results are those expected due to the sources of each influence. The main sources of the acoustic-related influences (acoustic and seismic) are located at the aft of the ships (propellers, blades and shafts). Also, the sources of the electric influence are located at the aft of the ships. The static magnetic influence is generated by the whole ferromagnetic mass, which is distributed along the ship but the alternating magnetic influence is generated at the aft of the ship

Similar analyses have been performed to obtain the correlation between influences. Due to the sources and propagation laws, the influences are defined as acoustics (acoustic and seismic) and no-acoustics (electric-magnetic).

Table 2. shows the mean value of the differences in seconds, in meters and in % relative to the length of the ships, between the time of the maximum of the amplitude module and the time of the maximum of the SPD module for the acoustic and non-acoustic influences .

Influence	Time (s)	Range (m)	% Length
Elec-Mag-DC	22	70	30
Elec-Mag-AC	3	11	5
Seis-Aco-DC	20	65	28
Seis-Aco-AC	31	99	43

Table 2. Mean value of the differences between the time of the maximum of the amplitude module and time of the maximum of the SPD module for acoustic and non-acoustic influences.

The highest level of correlation between influences is obtained for the non-acoustic influences in the frequency domain. The lowest correlation is obtained for the acoustic influences in the frequency domain. In the time domain, the correlation between acoustic and non-acoustic influences is quite similar.

These results are expected due to:

- The alternating electric and magnetic fields have common sources.
- The propagation medium of the acoustic and seismic influences is different. In particular, the sound speed is different in water than in sea bottom.

Finally, the analysis has been extended to the study of the correlation between the acoustic and non-acoustic influences in both, time and frequency domains. Table 3. shows the mean difference between the time of the maximum of the amplitude module (time domain) and the maximum of the SPD module for acoustic and non-acoustic influences separately.

Influence	Time (s)	Range (m)	% Length
Elec-Seis-DC	16	50	22
Elec-Aco-DC	27	86	37
Elec-Seis-AC	16	50	22
Elec-Aco-AC	31	101	44
Mag-Seis-DC	27	86	37
Mag-Aco-DC	39	126	54
Mag-Seis-AC	16	50	22
Mag-Aco-AC	31	101	44

Table 3. Mean difference between the time of the maximum of the amplitude module and the maximum of the SPD module for acoustic and non-acoustic influences in the time and frequency domains

According to the results, the seismic influence has higher correlation with the non-acoustic influences than with the acoustic influences, especially with the electric influence. The highest correlation is obtained between the seismic and electric/magnetic influences in the frequency domain. The correlation in frequency domain between electric/magnetic and seismic/acoustic influences is the same. The lowest correlation is obtained between electric/magnetic and acoustic influences in the frequency domain.

These results are those expected due to the sources of each influence. The main sources of the acoustic-related influences (acoustic and seismic) are located at the aft of the ships (propellers, blades and shafts). Also, the sources of the electric influence are located at the aft of the ships. The static magnetic influence is generated by the whole ferromagnetic mass, which is distributed along the ship but the alternating.

6 CONCLUSIONS

In this paper, a study of correlation of the multi-influence signature generated by cruise ships has been performed on a set of real measurements collected using the MIRS system manufactured by SAES.

The analysis is based on the computation of the time when the maximum of the module of the amplitude and the time when the maximum of the SPD module are achieved. The study includes:

- Analysis of correlation in time and frequency domain of each influence separately.
- Analysis of correlation between electric and magnetic and between acoustic and seismic influences.
- Analysis of correlation between acoustic and non-acoustic influences.

The study concludes that:

- The influence with the highest correlation is the seismic one.
- The highest correlation appears for the alternating electric and magnetic.
- The most correlated influences are the electric and seismic. The correlation between electric/magnetic and acoustic is low.

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